Background

In 1991, the General Conference (GC) in its resolution RES/552 requested the Director General to prepare ‘a comprehensive proposal for education and training in both radiation protection and in nuclear safety’ for consideration by the following GC in 1992. In 1992, the proposal was made by the Secretariat and after considering this proposal the General Conference requested the Director General to prepare a report on a possible programme of activities on education and training in radiological protection and nuclear safety in its resolution RES1584.

In response to this request and as a first step, the Secretariat prepared a Standard Syllabus for the Postgraduate Educational Course in Radiation Protection. Subsequently, planning of specialised training courses and workshops in different areas of Standard Syllabus were also made. A similar approach was taken to develop basic professional training in nuclear safety. In January 1997, Programme Performance Assessment System (PPAS) recommended the preparation of a standard syllabus for nuclear safety based on Agency Safely Standard Series Documents and any other internationally accepted practices. A draft Standard Syllabus for Basic Professional Training Course in Nuclear Safety (BPTC) was prepared by a group of consultants in November 1997 and the syllabus was finalised in July 1998 in the second consultants meeting.

The Basic Professional Training Course on Nuclear Safety was offered for the first time at the end of 1999, in English, in Saclay, France, in cooperation with Institut National des Sciences et Techniques Nucleaires/Commissariat a l’Energie Atomique (INSTN/CEA). In 2000, the course was offered in Spanish, in Brazil to Latin American countries and, in English, as a national training course in Romania, with six and four weeks duration, respectively. In 2001, the course was offered at Argonne National Laboratory in the USA for participants from Asian countries. In 2001 and 2002, the course was offered in Saclay, France for participants from Europe. Since then the BPTC has been used all over the world and part of it has been translated into various languages. In particular, it is held on a regular basis in Korea for the Asian region and in Argentina for the Latin American region.

In 2015 the Basic Professional Training Course was updated to the current IAEA nuclear safety standards. The update includes a BPTC text book, BPTC e-book and 2 “train the trainers” packages, one package for a three month course and one package is for a one month course. The” train the trainers” packages include transparencies, questions and case studies to complement the BPTC.

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Editorial Note

The update and the review of the BPTC was completed with the collaboration of the ICJT Nuclear Training Centre, Jožef Stefan Institute, Slovenia and IAEA technical experts.
# Module XIII: Maintenance Programme

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1 INTRODUCTION AND GENERAL REQUIREMENTS

**Learning objectives**

*After completing this chapter, the trainee will be able to:*

1. Explain the purpose of maintenance and maintenance programmes.
2. List elements of the maintenance programme.
3. List IAEA Safety standards relevant to maintenance.

Effective maintenance as well as surveillance and in-service inspection are essential for the safe operation of a nuclear power plant. They ensure not only that the levels of reliability and availability of all plant structures, systems and components (SSCs) that have a bearing on safety remain in accordance with the assumptions and intent of the design, but also that the safety of the plant is not adversely affected after the recommencement of operation.

To ensure that the overall maintenance is effective, nuclear power plants have comprehensive maintenance programmes, which include mutually supporting elements. These elements cover maintenance organization, maintenance activities, maintenance facilities and equipment, work procedures and record keeping, conduct and control of maintenance work, material condition, spare parts and procurement, and outage management. The primary purpose of comprehensive maintenance programmes is to ensure that equipment and components significant to nuclear safety, whose malfunction or failure could lead to radiation exposure of site personnel or members of the public, are ‘fit for purpose’ and provide the required functionality to enable safe and reliable power production.

High quality of the material condition of systems, structures and components (SSCs) is ensured through the use of an optimum balance of various types of maintenance based on prevention of failure occurrence and correction of failures. All maintenance work is properly authorized and accomplished through the use of technically simple, effective, safe and efficient procedures and work guidance documents. Maintenance typically includes a work management process that supports the completion of maintenance tasks in a safe, timely and productive manner.

Good coordination is established among different maintenance groups (mechanical, electrical, instrument and control, and civil), and with operations and supporting groups (fire protection, radiation protection, physical security, industrial safety, etc.). Plant equipment is only released from service for maintenance with the authorization of designated operations staff. Control room operating personnel are directly responsible for the safe operation of the plant, including its continued configuration control, and must be informed (by means of a
work permit procedure, for example) of all work in the nuclear power plant. Following maintenance, the equipment is returned to service after a test if necessary and a documented check of its configuration.

All maintenance personnel must keep in mind the importance to safety of the tasks they are performing and of the potential safety consequences of technical or procedural errors. The maintenance personnel who maintain equipment at the power plant must go through craft-specific training to become qualified to perform plant maintenance. Engineers at the power plant are often responsible for specific systems at the plant and manage the work done (preventive maintenance, repairs and modifications) on their system. All training programmes are inspected and certified.

Arrangements are established to procure, receive, store and issue spare parts and materials for use in the plant. The spares must have the same technical standards and quality requirements as the installed plant items (for more, see Quality Assurance for Safety in Nuclear Power Plants, in particular, the Safety Guides GS-G-3.1 and GS-G-3.5). Parts which have a limited lifetime should be replaced on schedule. This is to ensure their suitability for the expected service when needed.

![Figure 1.1: Maintenance during an outage.](image)

Most maintenance work is done during plant outages (Figure 1.1). Every year to two years the power plant is shut down for an outage, which lasts from 30 to 60 days, depending on the amount of major maintenance to be done. Outages are used to perform activities that cannot be done when the plant is operating:

- Reactor refuelling and other preparations (removal of reactor
head, upper internals),

- Preventive maintenance of equipment that runs continuously, for example the turbine-generator, which is inspected every 5 to 10 years; the transformers are also checked at each outage,
- Modifications or replacements of major equipment, such as the steam generator, which cannot be shutdown.

During an outage many activities are performed by contractors and other personnel who are not permanent employees of the plant and have to be supervised by means of established management systems. These systems cover the training and qualification of contractor personnel, radiation protection, familiarity with and adherence to procedures, understanding of plant systems, and applicable administrative procedures for both normal operation and emergency conditions. Contractor personnel must be made aware of their responsibilities in relation to the safety of the plant and the equipment they maintain. However, the operating organization is responsible for plant safety and for ensuring that the contractors’ work is of the required quality.

All activities of maintenance, testing, surveillance and inspection are recorded, stored and analysed. The analysis confirms if performance is in accordance with design assumptions and with expectations on equipment reliability.

Following any abnormal event, the operating organization is required to revalidate the safety functions and the structural and functional integrity of any SSCs that may have been challenged by the event. Necessary corrective actions are required to include in-service inspection, testing and maintenance as appropriate.

The recommendations and guidance for maintenance activities that are necessary to ensure that SSCs important to safety are capable of performing as intended are contained in Safety Guide NS-G-2.6. This Safety Guide supplements Section 8 of the Specific Safety Requirements Publication SSR-2/2 on the Safety of Nuclear Power Plants: Commissioning and Operation, which relates to the maintenance, surveillance and in-service inspection of SSCs important to safety.
2 TYPES OF MAINTENANCE

Learning objectives
After completing this chapter, the trainee will be able to:
1. Explain the purpose of preventive maintenance.
2. List the different types of preventive maintenance.
3. List some of the tools for predictive maintenance.
4. Describe the purpose of corrective maintenance activities.

While there are various conceptual approaches to maintenance, the relevant activities may be divided into preventive and corrective maintenance. A considerable part of all maintenance activity is performed while the plant is shut down; however, maintenance may be planned and executed under power operation provided that adequate defence in depth is maintained.

When you drive a car, you depend a lot on the sounds, the feel of the steering wheel and the instruments to determine if the car is running correctly; similarly with the operating equipment at a power plant - if sounds or vibration of the equipment or the instruments and test equipment indicate a problem or degradation, actions are taken to correct the deficiency. If the equipment fails to start or run, more immediate actions are taken. In some cases, regulations called technical specifications require the plant to be shut down if the equipment is not corrected within a certain period of time. The length of time depends on the safety significance of the equipment.

2.1 Preventive maintenance

Preventive maintenance includes periodic, predictive and planned maintenance activities performed prior to failure of an SSC so as to maintain its service life by monitoring degradation or preventing its failure:

- Periodic or time-based maintenance activities are accomplished on a routine basis and include any combination of external inspections, alignments or calibrations, internal inspections, overhauls, and replacements of components or equipment.
- Predictive or condition-based maintenance involves continuous or periodic monitoring and diagnosis in order to predict equipment failure. Not all equipment conditions and failure modes can be monitored, however; predictive maintenance should therefore be selectively applied where appropriate. Predictive techniques includes condition monitoring, reliability centred maintenance and similar techniques.
- Planned maintenance activities are performed prior to unacceptable degradation or equipment failure and are initiated on the basis of the results of predictive or periodic maintenance, vendor recommendations or experience.
Next a list of potential condition monitoring technologies (tools for predictive maintenance), as examples, will be briefly presented. Each technology is limited to specific types of equipment and is useful in identifying specific types of problems.

**Vibration analysis**

Vibration analysis is used to determine the operating condition of rotating equipment (e.g. turbines, motors, pumps), identifying developing problems before they cause serious failures and unplanned shutdown. Problems can include deteriorating or defective bearings, mechanical looseness, worn or broken gears, misalignment or imbalance. Vibration monitoring can be periodic, utilising portable vibration probes and data collectors, and may also be done with a permanently installed system. A continuous vibration monitoring system has the capability to assist the vibration specialist in not only tracking but also diagnosing vibration-related problems.

**Shock pulse method**

The shock pulse meter using a piezoelectric accelerometer detects the mechanical shock waves caused by the impact of two masses, without being significantly influenced by factors such as background vibration and noise. The method can be used to identify subtle changes in any rolling element bearing condition or lubrication, prior to substantial bearing deterioration or failure (e.g. rotating machinery with anti-friction bearings, motors, large pumps, turbines).

**Oil analysis**

Oil analysis can be used on machines that have a circulating oil system (e.g. turbines, generators, hydraulic systems, diesel engines) to identify the condition of fluids and lubricants, and determine if they are suitable for continued use or should be changed. It usually consists of periodically sampling selected oil streams for detection of particulates or contaminants that can indicate bearing failure, overheating, or other machine problems. Analysis of oil samples is usually done off-site, and following the data trend over time will indicate the component condition, and can be used to predict the optimum time and mode of corrective actions.

**Wear debris analysis and ferrography**

Wear debris analysis can be used to determine the type, location and severity of component wear occurring within the lubrication or hydraulic system. It is based on periodic sampling or in-line measurement. Debris analysis allows the number, size, composition and shape of ferrous and some non-ferrous wear particles to be determined.

**Acoustic leakage monitoring**

A compressed gas or fluid forced through a small opening creates turbulence with strong ultrasonic components on the downstream side of the opening, which is detectable with a scanning ultrasound device.
In steam, air or pneumatic, hydraulic and vacuum systems, acoustic monitoring enables the identification of leaks and improper seal or gasket installation. Poorly seated valves can also be detected. Leak detection systems can be permanently installed with the functions of alarming, trending and approximating the leak location, or simple portable devices employed.

**Thermography**
Thermographic analysis using infrared scanners provides a non-contact temperature indication for components such as bearings, motors, electrical connections, or conductors. This information can be particularly important in electrical equipment where circuits and connections may show no visible signs of deterioration until moments before a complete failure. Thermography can also detect cracks or deterioration in roof or wall insulation as well as in concrete structures, faults which can increase heat loss. A thermographic programme usually utilises a walk-around survey procedure.

**Computer modelling for Erosion/Corrosion analysis**
The computer simulation of erosion/corrosion is applied to predict the state and enable the well timed replacement of sections of carbon steel pipe. Such computer simulation takes into account:
- the size and geometry of the pipes,
- the type of medium,
- relevant parameters,
- the chemical composition,
- time.

**Visual inspection**
Visual observation, listening and touching are the oldest and most common condition monitoring techniques. In many cases human observation helps to identify a problem that is undetected by other predictive techniques or maintenance inspections. This can include loose, visibly worn or broken parts, oil leaks, chattering gears or hot bearing housings.

**Plant performance monitoring**
Performance monitoring or trending can be used on any equipment or component with permanently installed instruments which measure pressure, temperature, flow, rpm or electrical power consumption. It can also include readings taken by portable instruments on less critical components. The real value of performance trend data is to confirm a problem identified by other monitoring techniques, and provide further information on the location or seriousness of the problem. The advantage of performance trending is that the data is usually readily available and relatively inexpensive to collect.
2.2 Corrective maintenance

Corrective maintenance includes actions that, by means of repair, overhaul or replacement, restore the capability of a failed SSC to perform its defined function within the acceptance criteria.

2.3 Questions

1. Which types of maintenance activities does preventive maintenance include and what is their purpose?
2. Give some examples of tools for predictive maintenance.
3. Which actions does corrective maintenance include?
3 MAINTENANCE PROGRAMMES

Learning objectives
After completing this chapter, the trainee will be able to:
1. Explain the purpose of maintenance programmes.
2. Describe the difference between predictive, preventive and corrective maintenance programmes.
3. Explain the purpose of in-service inspection and plant ageing programmes.
4. Explain the interrelationship between maintenance, surveillance and in-service inspection.

3.1 Introduction

The maintenance programme for a nuclear power plant covers all the preventive and remedial measures, both administrative and technical, necessary to identify, prevent and/or mitigate degradation of a functioning structure, system or component (SSC), or to restore the design functions of a failed SSC to an acceptable level. The range of maintenance activities includes servicing, overhaul, repair and replacement of parts and may include, as appropriate, testing, calibration and in-service inspection. Typical relationships among these basic components and types of maintenance are shown in Figure 3.1.

![Figure 3.1: Strategic maintenance relationships.](image)

The operating organization is required to prepare and implement a programme of maintenance for those SSCs which are important to safety. This programme is in place prior to fuel loading, and full details of it are available to the regulatory body. The operational limits and conditions as well as any other applicable regulatory requirements are taken into account in the programme and are re-evaluated as...
necessary in the light of experience. Recent scientific and technological advances are also taken into consideration.

General objectives for a maintenance programme include:

- Proper maintenance of plant equipment is essential for the safe, reliable and efficient performance of a nuclear power plant. Senior management encourages a high level of maintenance by setting high standards, such as success criteria and performance indicators.
- The selection and training of maintenance personnel are well established so that a high quality of maintenance standards and activities can be achieved. Sufficient resources are provided and the planning and progress reporting are such that any workload backlog is kept to a minimum.
- Maintenance facilities and equipment are appropriate and sufficient to perform maintenance activities effectively. All maintenance activities from the planning stage to execution are carried out in such a manner that the radiation exposure of both site personnel and the general public is kept as low as reasonably achievable (ALARA).

### 3.2 Maintenance programmes

The maintenance programmes include programmes for in-service inspection, plant ageing and predictive, preventive and corrective maintenance, which together optimize safe and reliable performance of plant systems and components over the lifetime of the plant. These programmes are fully integrated with plant operation and modification activities. They are routinely reviewed and updated, as required, to take into account on site and off site operating experience and modifications to the plant or its operating regime.

The frequency of preventive and predictive maintenance, testing, surveillance and inspection of individual structures, systems, and components is determined by:

- Their relative importance to safety,
- Inherent reliability,
- Assessed potential for degradation during operation and ageing characteristics,
- Operational experience,
- Manufacturer’s recommendations.

**Preventive maintenance programme**

Preventive maintenance (PM) minimizes the potential for breakdown (corrective maintenance) of important equipment by the early detection and correction of equipment degradation. PM activities are scheduled and carried out according to a defined programme. The PM programme is periodically evaluated for effectiveness and, if appropriate, corrective actions are implemented. Appropriate reports
and records are kept, and maintenance history records are updated on the basis of PM activities.

**Predictive maintenance programme**

Predictive maintenance activities are used to monitor the condition of installed equipment and systems where appropriate. The results of predictive maintenance activities and surveillance tests are properly trended to promote the full effectiveness of the preventive maintenance and ageing (lifetime) management programmes.

**Corrective maintenance programme**

The corrective maintenance programme provides for effective reporting and timely correction of equipment degradation. Equipment deficiencies are promptly reported to the maintenance department for correction. Repairs to structures, systems or components are performed as promptly as practicable. Priorities are established, taking into account, first of all, the relative importance to safety of the defective structure, system or component. The status of reported deficiencies is adequately tracked and periodically reviewed to determine if corrective maintenance programme adjustments are necessary.

**In-service inspection programme**

The in-service inspection programme is established to examine systems and components of the plant, mainly those of the primary reactor coolant system, for possible deterioration so as to judge whether they are acceptable for continued safe operation of the plant or whether remedial measures should be taken.

**Ageing management**

The power plant also has an ageing programme that takes into account the plant equipment ageing process through the various activities of operation, surveillance and maintenance. The importance of ageing processes, addressing physical degradation of plant systems, structures and components as well as their obsolescence, for the safety and availability of a nuclear power plant is recognized in order to maintain and enhance the plant’s long term operating characteristics. Assessments are made of whether and how the ageing of SSCs would increase the potential for common mode failures and for varying levels of incipient, degraded and catastrophic failures, in order to provide assurance of the availability of aged SSCs important to safety until the end of their service life. The programme to manage the ageing process contains elements such as:

- Identification of components that are susceptible to ageing degradation that could affect plant safety;
- Adequacy of current methods for inspection, surveillance, maintenance and testing for the detection of ageing problems;
- Appropriate records to enable the ageing process to be tracked.
3.3 Interrelationship between maintenance, surveillance and in-service inspection

Maintenance is closely related to surveillance and in-service inspection, because they have a common objective, which is to ensure that the plant is operated in accordance with the design assumptions and intent, and within the operational limits and conditions. Maintenance, for example, is always followed by a series of tests. The results of surveillance or in-service inspection are compared with the acceptance criteria. If the results fall outside the acceptance criteria, corrective actions should be initiated. These actions include corrective maintenance measures such as adjustment, repair or replacement of defective items to prevent recurrence. These activities are planned and co-ordinated effectively. A common database is established in order to share relevant data and evaluations of results among the organizations that are involved in the planning and implementation of maintenance, surveillance and in-service inspection activities.

3.4 Questions

1. What do the general objectives for the maintenance programme include?
2. Which factors affect the frequency of maintenance, testing, surveillance and inspection of individual structures, systems, and components?
3. What does the corrective maintenance programme provide?
4. For which systems and components is the in-service inspection programme established?
5. What elements does the ageing management programme contain?
6. What is the common objective of maintenance, surveillance and in-service inspection?
4 ORGANIZATION AND FUNCTIONS

Learning objectives
After completing this chapter, the trainee will be able to:
1. Describe the organization of the maintenance department and its purpose.
2. Explain the purpose of training and qualification programmes.
3. List the factors which affect the organization of maintenance.
4. Identify what provides a representative view of maintenance performance.
5. Describe the functions of managers.
6. Explain why maintenance training and qualification programs are developed.

4.1 Organization and administration

The ultimate responsibility for preparing and executing an adequate maintenance programme rests with the operating organization. For every aspect of the programme, the operating organization assigns the authority and responsibilities, both within its own organizational structure and to other organizations, and specifies lines of communication. The plant management establishes a group (maintenance department) on site to implement the maintenance programme. The maintenance department is usually divided into mechanical, electrical, and control and instrumentation sections.

The organization for maintenance varies greatly between different operating organizations, depending on:
- the operating organization’s concepts and practices for operation,
- the type of reactor,
- the refuelling mode,
- the frequency of periodic shutdowns.

The organization and administration of the maintenance department ensures the efficient and effective implementation and control of maintenance activities. The organization and staffing of the maintenance department, as well as the responsibilities of the different maintenance units and its staff, are described in writing and must be understood by all affected personnel. Good coordination among different maintenance groups (mechanical, electrical, instrument and control, and civil works), and with operational and supporting groups, is established. Staff can be supplemented as necessary, so that duties relevant to nuclear plant safety and system reliability are carried out without undue haste or pressure.

The organization, qualifications and number of maintenance personnel must be sufficient for the maintenance performed during the operation
of the plant, the outage work to be performed by the plant's staff, and supervision of contractor's work during an outage. Contractor personnel are subject to the same criteria as plant personnel. Good initial and continuing training is implemented.

Maintenance personnel and their professional capabilities are the most valuable resource of the maintenance department. The full utilization of this resource requires:

- An organization which fosters teamwork through an attitude of trust, communication, and mutual respect.
- Encouraging open communication and seeking feedback on the effectiveness of policies and practices.
- Clear allocation of responsibilities to accountable identified individuals.
- That the organization evaluates its performance through self-assessment and takes self-initiated corrective actions for performance enhancements.
- That personal integrity and professionalism are a central part of every job.
- The maintenance managers give exemplarity through leadership.

The goals and objectives of the maintenance department are defined within the plant policies and objectives. Performance indicators are established and reported in periodic reports. Periodic maintenance indicator reports provide a representative view of maintenance performance and are useful to plant and maintenance management. There is a process in place, and effectively used to sustain maintenance policies and programmes consistent with current industry best practices.

In the maintenance area the following indicators have proved to be useful for monitoring performance:

- Number of outstanding backlogs;
- Number of non-proceduralized practices or ‘workarounds’ employed;
- Number of control room instruments out of service;
- Amount of maintenance rework;
- Percentage of spare parts which are available, or as expected, or on demand;
- Average time for corrective maintenance actions;
- A measure of the prevalence of human errors;
- Completion of training to agreed time-scales;
- Numbers of minor injuries and near misses (an increasing trend in the reporting of these is to be encouraged, since they frequently represent precursors to more serious accidents);
- Standards of housekeeping.

Managers explain their commitment to safety culture to their staff, remind them that haste and shortcuts are inappropriate, and adherence to written procedures is essential. Personnel are encouraged to suggest
improvements to safety, reliability, quality and productivity. Management regularly reviews personnel performance and safety attitudes and responds effectively to safety infringements and violations of technical specifications or procedures. Managers not only provide leadership but also develop, in partnership with staff, the means of translating the safety goals of the organization into day-to-day reality. Managers and supervisors tour the plant regularly to check plant status and maintenance activities.

Interfaces with supporting on-site and off-site groups are clearly defined and working well. There is good coordination among the various maintenance groups and an effective interface with the operations department and other plant groups.

Co-ordination with contractors is effective and well regulated, with clearly established roles and responsibilities for contractors and their plant counterparts. The experience level and proficiency of maintenance workers and contractors is appropriate for their assignments. Workers are knowledgeable of current work practices and plant procedures.

Typical documents including the organization and functions of maintenance are:
- The plant organization chart including functional responsibilities.
- The maintenance department organization chart, including interfaces with other organizational units.
- The plant nuclear safety policy.
- Plant Human Performance tools applied to maintenance activities.
- Maintenance training programmes.
- Plant maintenance policies.
- Maintenance programme manuals and procedures.
- Maintenance department programme descriptions.
- Maintenance personnel functions and responsibilities.
- The goals and objectives of the maintenance department.
- Maintenance department performance indicator results.
- Maintenance department performance reports.
- Operating experience in maintenance activities.

### 4.2 Training and qualification of personnel

The training and qualification of personnel is integrated into a relevant programme at the plant and is based on an approved and documented process which is traceable.

Training and qualification programmes are primarily reviewed by an expert who evaluates them and are developed to maintain the
knowledge and skills needed to effectively perform maintenance activities. The special training provided to individuals develops their craft skills and ensures qualification on equipment to which they are assigned. There is a process which ensures that these qualification levels can be easily established and matched to the requirements of specific jobs.

The training programme also develops and maintains general knowledge of the nuclear power plant. The significance of items related to safety, safety risks involved in maintenance work and methods to minimize these risks are included. Operating experience is analysed for maintenance lessons to be learned. These lessons are subsequently incorporated in the training in a timely manner. Maintenance management personnel are actively involved in the design and review of training. This is achieved by regular meetings between training and maintenance management and involvement in the training.

### 4.3 Questions

1. Which factors affect the organization of maintenance?
2. What provides a representative view of maintenance performance?
3. What are the functions of managers?
4. Why are maintenance training and qualification programmes developed?
Module XIII: Maintenance programme

5 MAINTENANCE FACILITIES AND EQUIPMENT

Learning objectives
After completing this chapter, the trainee will be able to:
1. Explain the purpose of working facilities.
2. Explain the purpose of facilities for maintenance of radioactive items, decontamination facilities and mock-ups.
3. Explain the purpose of special equipment and tools.

The working facilities provide sufficient space and equipment to perform maintenance activities efficiently. Maintenance facilities are clean and orderly, and maintenance tools and equipment are maintained in good repair.

5.1 Maintenance facilities

The size and arrangement of maintenance facilities promotes the safe and efficient completion of work. Facilities are provided for work on both contaminated and uncontaminated equipment. Adequate training facilities, with necessary mock-ups, are available and used to support training for complex or major maintenance tasks.

Workshop facilities
On-site workshops are provided for mechanical, electrical, control and instrumentation equipment.

Each of the workshops is equipped with the following:
- An office area, including facilities for the processing and storage of records and procedures;
- A fitting and overhaul area with suitable work benches for the disassembly, repair and reassembly of those plant items that are intended to be dealt with in the workshop;
- Secure storage facilities for special tools and testing equipment needed for maintenance.

Workshops are designed to take into account some specific rules for the use and storage of and work with special products; e.g. separation of carbon steel and stainless steel storage and work areas (welding, grinding...), use of halogen-free products, etc. These rules aim to avoid potential corrosion or stress-corrosion problems in the medium/long term.

Facilities for maintenance on radioactive items
It is impracticable or impossible to decontaminate some plant items sufficiently to allow them to be maintained in the workshops for clean items. So special facilities are provided for the maintenance of
contaminated items, in order to keep radiation doses to individuals as low as reasonably achievable and to prevent the spread of contamination. This is accomplished by providing specific maintenance facilities for particular plant items and by providing workshops located within the controlled area for work on radioactive parts brought to them.

**Decontamination facilities**
Adequate decontamination facilities for removing radioactive contamination from plant items, tools and equipment prior to their maintenance are available and used to minimize radiation doses and exposure to contamination. They include the following features:

- access control and changing rooms;
- ventilation with discharge filters;
- handling, storage and disposal of liquid radioactive waste;
- handling, storage and disposal of solid radioactive waste;
- equipment for radiation monitoring and radiation protection;
- decontamination tanks and special equipment capable of decontaminating the largest plant items likely to require decontamination;
- an adequate electric power supply and adequate supplies of steam, hot water, compressed air and appropriate chemical decontaminating agents;
- other decontamination systems, such as those for glass blasting or ultrasonic techniques.

**Mock-ups**
In some cases, there are advantages for maintenance in designing and constructing simulations, mock-ups or models of particular sections of the plant, in areas remote from the section of the plant concerned. Mock-ups are considered in particular for:

- rehearsing work to be carried out in high radiation areas or on highly contaminated plant items, particularly for personnel not familiar with the plant or for an unusual or specialized task;
- preparation and validation of procedures, to avoid errors and reduce exposure;
- gathering of experience with tools and protective equipment;
- development and improvement of tools and equipment;
- training and qualification of personnel for specific work, and confirmation of estimates for work durations.

**5.2 Tools and equipment**
Proper tools, equipment and consumable supplies are available to support work, and contaminated tools and equipment are adequately marked and segregated in a manner which prevents the spread of contamination. Special tools, jigs, fixtures, etc., are identified and stored to permit retrieval when needed. Unserviceable tools and equipment are identified to prevent use.
Measuring and test equipment is calibrated and tested adequately to ensure accuracy and traceability. Test equipment that is out-of-tolerance is removed from service.

The plant management provides special equipment where this could significantly reduce exposure or enhance safety, and provides adequate training in its use. Remote controlled tools are used, as appropriate, to minimize radiation exposures. Examples of special equipment are:

- remote handling manipulators and remotely operated special purpose tools;
- automatic welding and cutting equipment;
- remotely operated non-destructive testing equipment;
- automatic in situ valve seat lapping machines;
- remote viewing equipment such as mirrors, binoculars, telescopes, periscopes, boroscopes, fibrescopes, closed circuit television and remotely operated cameras;
- communication systems such as direct line telephones and radio, and communications equipment for use when protective respiratory equipment is being worn;
- special containers for contaminated items;
- shielded containers and portable shielding;
- protective clothing and equipment, possibly incorporating advanced dosimetric technique, for increasing awareness of occupational exposure and improving its management;
- material and equipment for controlling and containing radioactive contamination (for example, plastic sheeting and tents, paper floor covering, suction cleaners and floor cleaning equipment);
- fixed or rapidly assembled equipment for access in order to reduce personnel exposure (for example, permanent ladders or telescopic cradles).

Typical documents listing maintenance equipment and conditions are:

- General site layout plan showing the locations of all maintenance facilities (workshops, workshops in controlled areas, decontamination facilities etc.);
- List of special equipment (mock-ups, remote handling manipulators, tools, automatic welding and cutting equipment);
- Equipment calibration records.

### 5.3 Questions

1. For which equipment are on-site workshops provided?
2. How is each workshop equipped?
3. Which maintenance facilities are designed to deal with radioactive items?
4. For what in particular are mock-ups considered?
5. Where is special equipment used?
6. Which typical documents show maintenance equipment and conditions?
6 PROCEDURES, RECORDS AND HISTORIES

Learning objectives

After completing this chapter, the trainee will be able to:
1. Explain why procedures and work instructions are used.
2. Explain the purpose of using a maintenance history.

6.1 Introduction

Maintenance procedures and other work-related documents provide appropriate directions for work and are used to ensure that maintenance is performed safely and efficiently.

Maintenance instructions issued to craftsmen are compiled in accordance with quality assurance requirements and point out the impact of the work on nuclear safety. The required level of skill and methods of procedure use are stated.

A maintenance history is used to support maintenance activities, upgrade maintenance programmes, optimise equipment performance and improve equipment reliability. Appropriate arrangements are made for orderly collection and analysis of records and production of reports on maintenance activities. Maintenance history records are easily retrievable for reference or analysis. The use of computerized maintenance history handling is common.

Examples of documents showing procedures, records and histories:
- Administrative procedure for the preparation and issuance of maintenance procedures and work instructions;
- Safety-related corrective maintenance procedures;
- Preventive maintenance procedures;
- Predictive maintenance procedures;
- Work authorization instructions;
- Equipment troubleshooting procedures.
- General administrative procedural controls or general safety instructions;
- Administrative procedures on maintenance history keeping;
- Maintenance history files;
- Setpoints register (instrument calibration figures, relief valve settings, electrical plant protection settings etc.);
- Quality assurance procedure for set point registration;
- Root cause analyses of component failures.
6.2 Procedures and records

Appropriate procedural controls and safety instructions are specified for maintenance activities. The preparation, review, approval and revision of procedures and other work related documents are properly supervised. Documents used in lieu of procedures (such as excerpts from vendor manuals) receive the same review and approval as procedures.

Procedures are normally prepared in co-operation with the designers, the suppliers of plant and equipment, and the personnel conducting activities for quality assurance, radiation protection and technical support.

Procedures and work instructions used to perform maintenance activities are technically accurate, easy to understand, up to date and readily available to the users.

Detailed work instructions include the following, where appropriate:
- Identification of the plant system and components to be maintained;
- Specification of the necessary tools, material and equipment;
- Sufficient guidance for the task to be performed in a safe, practical and efficient manner, including personnel qualifications as appropriate;
- Breakdown of the task into sequential steps with sufficient detail for the work to be done by a competent person without direct supervision.
- Adequate drawings and illustrations;
- Identification of special tools or techniques needed at appropriate steps in the sequence;
- Details of interfaces with work carried out by other personnel;
- Warnings of potential dangers to plant or personnel and clear specification of precautions to be taken;
- Radiation protection provisions;
- Identification of hold points where progress to the next step is dependent upon an independent review;
- Inspection instructions and related acceptance criteria,
- A process to record the identification numbers of test equipment, torque wrenches and quality assured spare parts used during the activity.

Beside detailed work instructions procedures typically include the following:
- Identification of the procedure using numbers, letters or a combination of both that identify each procedure as one in a series. This unique identification code is used to identify the procedure in all subsequent programmes, plans and records that refer to it.
- Title: a concise description of the subject of the procedure.
- Purpose: a brief statement of the purpose and scope of the activity involved in the procedure.
- Prerequisites: all special conditions for the plant or system, or the status of equipment necessary prior to the commencement of work covered by the procedure. Any necessary special training or mock-up practice is also mentioned.
- Limiting conditions: any conditions, such as load reduction or the operation of standby equipment or safety systems, that result from carrying out the work and which limit the plant’s operations. For example, when a system is undergoing repair, surveillance or testing, it is considered unavailable for safety purposes unless it is demonstrated to be able to perform its safety function to an acceptable degree.
- Return to service: the actions and checks necessary for returning the equipment or system to an operational condition after the person responsible has certified that the task is completed. Where appropriate, independent checking and acceptance criteria are specified. These criteria include correct reinstatement and correct compliance with procedures, as well as confirmation of system operability (for example, confirmation of valve line-up).
- Operational testing: any operational testing subsequent to a job that is necessary to prove that the equipment is functioning in the intended manner.

The last two items are operating functions and are included either in the maintenance procedure or in a special interfacing operating procedure.

An effective programme exists to review procedures periodically for technical accuracy, human factors, and the inclusion of in-house and industry operating experience. Temporary changes to procedures are sufficiently regulated, including an appropriate review and approval.

### 6.3 Maintenance history

Adequate history records are maintained for systems and equipment important to plant safety and reliability. The documentation of maintenance work and inspection/test results must be complete. The maintenance history records are retrievable and secure.

Maintenance histories are periodically reviewed and analysed to identify adverse equipment performance trends and persistent maintenance problems, to assess their impact on system reliability, and to determine root causes. The resulting information is used to improve corrective and preventive maintenance on all affected equipment. Maintenance is adequately documented and the root causes are properly identified.
6.4 Questions

1. Who participates in the preparation of procedures?
2. What do detailed work instructions include?
3. Why are maintenance histories periodically reviewed and analysed?
7 CONDUCT AND CONTROL OF MAINTENANCE WORK

Learning objectives
After completing this chapter, the trainee will be able to:
1. Describe the conduct of maintenance work.
2. Explain the purpose of the work planning and control system.

7.1 Conduct of maintenance

Maintenance is conducted in a safe and efficient manner to support plant operation. Personnel exhibit professionalism and competence, which results in quality workmanship in performing assigned tasks.

Maintenance personnel are attentive to identifying and responsive to correcting plant deficiencies with the goal of maintaining equipment and systems in operation and in optimum material condition.

The conduct of maintenance work in the plant must incorporate all of the programme elements related to the task being performed. For example:

- Work authorization procedures.
- A flow diagram for general work control procedure.
- An industrial safety manual.
- Industrial safety event reports.
- Radiological work practice procedures.
- Radiological event reports.
- Licence event reports involving maintenance activities.
- During the work e.g. in contaminated, controlled areas particular attention is paid to the following items so that they are consistent with plant policy and good industrial practices:
  - Use of maintenance procedures and work documents.
  - Use of tools and support equipment.
  - Foreign material exclusion practices.
- Equipment isolation and tagging practices.
- Control of materials, spare parts and replacement equipment.
- Human performance practices including a pre-job briefing with support groups such as radiological protection, quality control and stores, “minute stop”, etc.
- Industrial safety practices (hard hats, scaffolding, safety belts, ear protection, safety glasses, confined space entries and unique hazards).
- Radiological safety practices, including the use of protective clothing, respiratory equipment, and forced air hoods.
- Work site cleanliness and orderliness.

Maintenance work is started only after obtaining necessary
authorizations (work permit, fire permit, specific zones access permit, etc.), and is performed by qualified personnel. Adequate resources are available for maintenance during day and night shifts. Procedures which include hold points for independent quality control inspection are followed, and procedural problems are promptly resolved.

Managers and supervisors routinely observe maintenance activities and ensure adherence to station policies and procedures. The work groups are instructed on specific jobs, are knowledgeable of any special requirements, and are aware of the impact of their jobs on nuclear safety.

Contractors and other non-utility personnel conducting plant maintenance operate under the same control procedures and to the same standards as plant maintenance personnel and are properly supervised. Contractors working on safety-related SSCs are selected and qualified by the plant, and trained to the same standards as plant personnel.

Appropriate personnel (e.g. operations, engineering and maintenance) perform post-maintenance testing, document and review the results, and return equipment to service only when it is fully ready.

An adequate clearance (tagging) system is in use for the protection of equipment and the safety of personnel during maintenance. Personnel understand and use the clearance system correctly and are safety conscious in the conduct of their work and use safety equipment as appropriate.

### 7.2 Work control

A comprehensive work planning and control system applying the defence in depth principle is implemented so that work activities can be properly authorized, scheduled and carried out by either plant personnel or contractors, in accordance with appropriate procedures, and can be completed in a timely manner. The work planning system maintains a high availability and reliability of important plant SSCs.

The comprehensive work control system includes any authorizations, permits and certificates necessary to help ensure safety in the work area and to prevent maintenance activities from affecting other safety relevant areas. The following specific matters are considered in the work control system:

- work order authorizations;
- equipment isolation, work permits and tagging;
- radiation work permits;
- industrial safety precautions;
- drainage facilities and ventilation;
- fire hazard control;
- electrical and mechanical isolation devices;
- control of plant modifications.

The effectiveness of the work control process is monitored via appropriate indicators (such as repeated work orders, individual and collective radiation doses, the backlog of pending work orders, interference with operations) and corrective action taken when required. Plant defects should be tracked to completion and records kept of work performed. The work control process contains an effective operational feedback system and a systematic analysis of root causes of rework or repetitive failures.

The work control system ensures that plant equipment is released from service for maintenance, testing, surveillance and in-service inspection only upon authorization of designated operating personnel and in compliance with the operational limits and conditions. It also ensures that, following maintenance, testing, surveillance and in-service inspection, the plant is returned to service only upon completion of a documented check of its configuration and, where appropriate, of a functional test.

Regular maintenance and operations staff meetings are held concerning maintenance priorities and work scheduling. The system prioritizes work, therefore the most important work is done before more routine work items and the backlog of work is effectively managed. Scheduling and co-ordination of work avoids unnecessary removal of systems and equipment from service, and uses manpower efficiently. Work scheduling allocates parts, materials, resources and expertise at the appropriate time for completion of the preventive and corrective programmes. Post-maintenance testing requirements are clearly defined and acceptance criteria are adequately specified.

Radiation dose accumulation is effectively monitored during performance of high-dose work, and appropriate dose controls are in place.

The work planning system provides management with an accurate status of outstanding maintenance work, planned maintenance and completed maintenance. Temporary repairs are minimized and replaced by permanent repairs when conditions permit. Temporary repairs are well identified and documented.

### 7.3 Questions

1. What is necessary before maintenance work can be started?
2. What are the functions of managers and supervisors in conducting maintenance work?
3. Which specific matters are considered in the work control
4. What has to be done before equipment is returned back to service?

5. What does the work control system provide for management?
8 MATERIAL CONDITIONS

Learning objectives
After completing this chapter, the trainee will be able to:
1. Explain the purpose of maintaining good material conditions.
2. List some examples of good material conditions.

The material condition of the plant is maintained in such a way that safe, reliable and efficient operation of the plant can be ensured. Plant managers and supervisors define the required standard and conduct frequent tours of plant areas in order to confirm that high standards are maintained. Supervisory tours of the plant are effective and help to enforce high material condition standards.

Typical documents including material conditions are:
- Plant material condition reports;
- Work requests for corrective maintenance;
- Schedule for management tours of plant facilities;
- Documented follow-up of the results of management tours, and corrective actions issued;
- Backlog of corrective actions programme.

All deficiencies are identified, controlled, eliminated and reported to the main control room. The storage and use of combustible and chemical materials conform to safety standards and plant procedures. Protective measures for safety hazards are adequate.

8.1 Examples of good material conditions

Systems and equipment in the nuclear power plant should be in good working order. Examples of this include the following:
- Temporary modifications and repairs are minimized. A procedure should exist to evaluate, control and track temporary repairs;
- Fluid system leaks are minimized and identified, and controlled leaks should be segregated to avoid personnel and damage to equipment;
- Equipment is appropriately protected from adverse environmental conditions. Wiring and terminals should be protected and undamaged and cable trays should be in good condition;
- A procedure exists to ensure instruments, controls and associated indicators are calibrated as required to maintain the appropriate degree of accuracy. Indicators are not out of scale or inoperable. Recorders function correctly and paper is available;
- Good lubrication practices are evident;
- Fasteners and supports are properly installed and in the “as designed” position; pipes do not move excessively;
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- Equipment, structures and systems are properly preserved, insulated, free of corrosion and earthing (grounding) cables are securely fastened where necessary;
- Thermal insulation is in good condition;
- Rotating equipment is appropriately protected and does not vibrate excessively. Chain or belt drives are properly adjusted;
- Filters and strainers are not clogged; they are checked by observing excess differential pressure and conducting visual checking when possible;
- Leaks are collected, tagged and followed;
- Fire barriers are effective, e.g. fire doors able to close, electrical cabinet doors and panels closed and secured;
- Valves have sufficient packing to allow tightening. Valve stems are properly lubricated;
- Hoses are in good condition and show no evidence of leakage;
- System and component labelling is consistent, accurate and easy to read;
- Stairs and ladders are properly secured;
- Lighting is adequate and in good repair;
- Paint and coatings are in good condition;
- Access to emergency equipment is clear.

8.2 Questions

1. What are the functions of managers and supervisors in achieving good material conditions?
2. Give some examples of good material conditions.
9 SPARE PARTS AND MATERIALS

Learning objectives

After completing this chapter, the trainee will be able to:

1. Explain what materials management ensures.
2. Describe the procurement, storage and control of spare parts.
3. Understand the importance of preventing counterfeit, fraudulent and suspect items (CFSI) from entering the facility, and in identifying and disposing of CFSI that already exist.

Materials management ensures that necessary parts and materials, meeting established quality or design requirements, are available and appropriate when needed. Suitable organizational units are established to procure, receive, store and issue materials, spare parts and components for use in the plant. Spare parts and materials important to safety are accompanied by documentation certifying that all requirements specified in the purchase order have been met.

Typical documents showing spare parts management are:

- Procurement, receipt, storage and issue procedures;
- Samples of purchase orders and specifications;
- QA documentation.

9.1 Procurement

The responsibility for procurement, receipt, storage and issue of spare parts and materials is clearly defined. Procurement specifications are clear and unambiguous, include current technical and QA requirements and include the requirement that no substitutions of materials or components should be made without advising the purchaser. Storage and shelf life requirements are specified by the supplier.

Spares are purchased to the same technical standards and QA requirements as the equivalent installed plant items. Items are obtained only from suppliers who are qualified and approved in accordance with safety requirements. Selected spare parts, which are important to safety, have all the necessary certificates.

Receipt inspections of spare parts provide sufficient assurance of compliance with design, procurement specifications and QA requirements. The process for certifying commercial-grade material and parts for use in systems important to safety is appropriate.

Materials and parts needed for outages are ordered well in advance, so that the material is available on site and in time to support the outage schedule.
In an increasingly globalised world economy, with extended supply chains, there is increased opportunity for counterfeit, fraudulent and suspect items (CFSI) to enter the supply chain. Such items represent a very real risk to nuclear safety and it is important that regulators, licensees and their suppliers understand the potential for harm and the measures that are taken to protect and assure the integrity of items that have a nuclear safety function.

Management is responsible for providing the resources necessary to assure personnel have the knowledge and capability to prevent CFSI from entering the facility, and to identify and dispose CFSI that already exist in the facility. Therefore management is responsible for developing a quality assurance programme (QAP) that:

- Ensures that items intended for application in safety systems comply with the design, applicable specifications/standards and procurement documents.
- Identifies and disposes CFSI that create potential hazards in systems and applications.
- Reports discoveries of and shares information about CFSI within the facility and with external organizations.
- Trains managers, supervisors and workers on the prevention, detection and disposal of CFSI.
- Maintains current, accurate information on CFSI and associated suppliers using all available sources within the industry.
- Analyses CFSI information for trends.
- Obtains remedies from suppliers of CFSI.

Personnel are trained, within their respective areas of responsibility, to identify, prevent and eliminate the introduction of CFSI into the facility. Specific training is undertaken for:

- The detection of installed CFSI.
- Identifying CFSI during receipt and inspection.
- Using CFSI information within the procurement process.
- Including the potential for CFSI as a factor in component failures.

It is generally recognized that those facilities most effective in detecting CFSI have common characteristics:

- An engineering department that serves in a leadership role responsible for the tracking and evaluation of CFSI.
- Engineering staff involvement in procurement and product acceptance.
- Effective source inspection, receipt inspection, and testing programmes.
- Thorough, engineering-based programmes for review, testing and dedication of commercial-grade products for suitability in safety systems.
9.2 Storage and control

The material management facilities provide adequate support to the plant. Warehouse administration and the interface with maintenance planners are appropriate. Parts and materials are available when needed in the plant.

Materials are stored and identified in a manner that permits timely retrieval. Adequate stock records are maintained, purchase orders are tracked, and safety-related parts are readily traceable from purchase order to installation. Proper engineering approval is obtained for any deviations from design specifications for parts or material.

Storage facilities are operated in a manner that takes into account special environmental requirements for storing certain components. Spare parts with limited life are stored separately and clearly marked to indicate acceptable periods of use. Materials with special hazardous are properly segregated and adequate procedures are in place to regulate their receipt and use.

Preventive maintenance activities are performed on certain spare equipment (e.g. large rotating electrical motors). Appropriate minimum, maximum and reorder levels are defined for warehouse stock. Non-conforming and damaged spare parts are stored separately and regulated to prevent inadvertent use.

9.3 Questions

1. Which typical documents relate to spare parts?
2. What are the technical standards and QA requirements for spare parts?
3. From which suppliers are spare items obtained?
4. When are parts and materials needed for outages ordered?
5. What do CFSI represent to nuclear safety?
6. What are the characteristics of facilities that are most effective in detecting CFSI?
7. How are storage facilities operated?
8. How are damaged spare parts treated?
10 OUTAGE MANAGEMENT

Learning objectives
After completing this chapter, the trainee will be able to:
1. Describe what ensures effective outage management.
2. Describe outage organization.
3. Explain the purpose of planning and scheduling of outages.

10.1 Outage organization

Outage management organization and administration ensures the effective implementation and control of all activities during planned and forced outages. The tasks and responsibilities of different organizational units and persons are clearly defined in writing. This is especially important during outage periods when the organization of the facility is potentially temporarily modified. Nuclear safety during shutdown periods is given careful consideration.

The outage organization includes the outage managers and planners; it also includes appropriate plant or other company personnel assigned to provide increased supervisory coverage during the outage.

Typical documents specifying outage management practices are:
- A plant organization chart during outage periods.
- Administrative procedures for outage preparation, performance, control and review.
- An outage schedule.
- A plan of outage preparation meetings.
- An outage review report.

Interfaces between maintenance and other groups are clearly defined and operating personnel remain cognizant of maintenance, modification and testing activities.

The outage review report presents the lessons learned and recommendations for the next outage preparation. Improvement actions are taken in response to the report.

10.2 Planning and scheduling

Most maintenance work is done during the plant outages. Therefore, extensive preparation and detailed planning for planned outages are accomplished and a tracking system is used to monitor status and to ensure controlled execution of outage activities.

Outage planning is a continuing process in which account is taken of
past, next scheduled and future outages. Milestones are determined and used to track work prior to the outage. Planning is completed as far in advance as possible, since circumstances may necessitate the outage to begin earlier than intended. Outage planning staff include personnel with operational experience as well as experienced mechanical, electrical and instrumentation and control personnel.

Outage planning and scheduling activities provide for safe, timely and orderly completion of outage work. The following aspects are considered:

- Freeze dates are scheduled to limit growth of the scope of outage work. Adequate reviews are conducted to include work after freeze dates;
- System and equipment outages are scheduled to provide sufficient defence in depth for cooling the reactor core and to meet the operating limiting conditions;
- Personnel are trained for special outage work including the use of mock-ups where appropriate;
- Adequate provision of resources is allotted for operational testing at optimal points in the schedule.
- Coordination between operations, maintenance and other groups involved with outage work.
- Advance preparation and approval of maintenance and modification work packages, including work procedures, post maintenance and modification test procedures.
- Procurement of parts and materials.
- Scheduling and provision of manpower, equipment and services to support the work quality and the outage schedule.

ALARA principles and waste reduction programmes are taken into consideration during planning and scheduling of outages. High dose work is planned and co-ordinated so as to minimise radiation doses.

### 10.3 Questions

1. What does an outage review report present?
2. Which personnel participate in outage planning?
3. Which aspects are considered during planning and scheduling of an outage?
11 REFERENCES


The views expressed in this document do not necessarily reflect the views of the European Commission.